Class 4 ((Communication and Computer Networks))

Subject : Physical Layer and Media

Lesson 4... *Data and Signals Transmission*

Abstract

The physical layer, it is the layer that actually interacts with the **transmission media**, the physical part of the network that connects network components together. This layer is involved in **physically carrying information** from one node in the network to the next. One of the major functions of the physical layer is to move data in the form of electromagnetic signals across a transmission medium. In this lesson we will have a look about both data and signal that can be represented in either **analog** or **digital** form.

Key points;

- All of the forms of information that we use can be represented by electromagnetic signals, either analog or digital signals can be used to convey information.
- Any electromagnetic signal, analog or digital, is made up of a number of constituent frequencies. A **key parameter** that characterizes the signal is **bandwidth**, which is the width of the range of frequencies that comprises the signal. In general, the greater the bandwidth of the signal, the greater its information-carrying capacity.
- The designer of a communications facility must deal with four factors: the **bandwidth of the signal**, **the data rate** that is used for digital information, the **amount of noise** and other impairments, and **the level of error rate** that is acceptable. The bandwidth is limited by the transmission medium . The **data rate** is limited by the bandwidth, by the presence of impairments, and by the error rate that is acceptable.

- **DATA:** Entities convey meaning or information.
- **SIGNAL:** Any electrical quantity such as voltage, current or frequency can be used to transmit information.

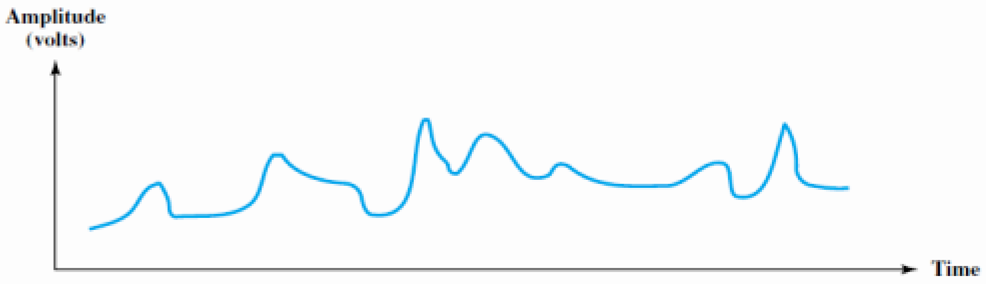
Frequency, Spectrum, and Bandwidth

Electromagnetic signals is a signal that generated by the transmitter and transmitted over a medium. It is a function of time, but it can also be expressed as a function of frequency; that is, the signal consists of components of different frequencies. The **frequency domain** view of a signal is more important to an understanding of data transmission than a **time domain** view.

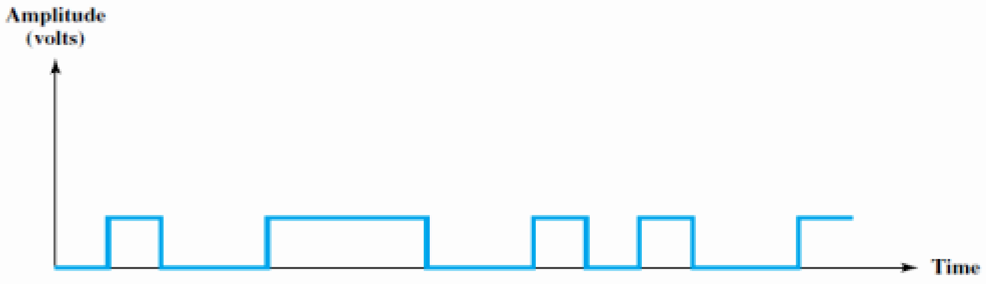
Time Domain Concepts

Viewed as a function of time, an electromagnetic signal can be either analog or digital. An **analog signal** is one in which the signal intensity varies in a smooth fashion over time.

A **digital signal** is one in which the signal intensity maintains a constant level for some period of time and then abruptly changes to another constant level. Figure below shows an example of each kind of signal.

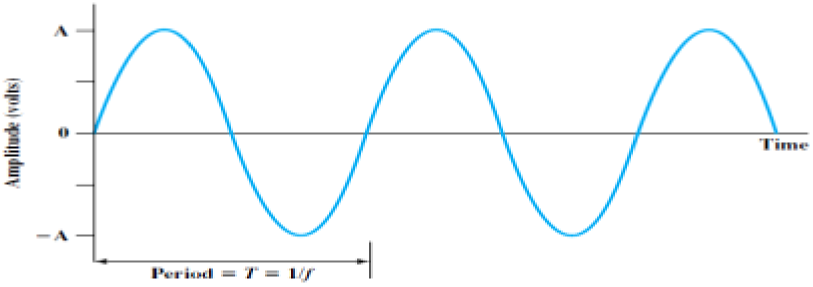


(a) Analog

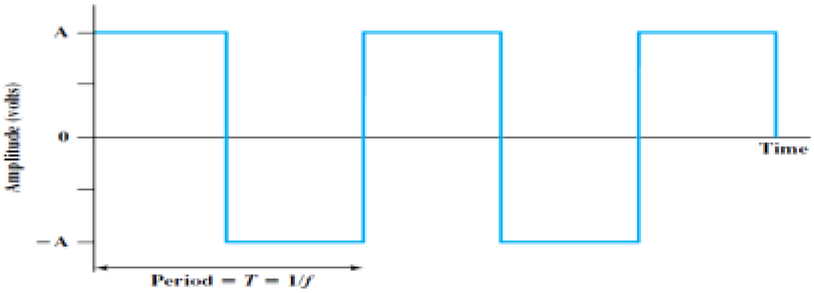


(b) Digital

The frequency is the rate [in cycles per second, or Hertz (Hz)] at which the signal repeats. An equivalent parameter is the **period** (T) of a signal, which is the amount of time it takes for one repetition; therefore T=1/f,



(a) Sine wave

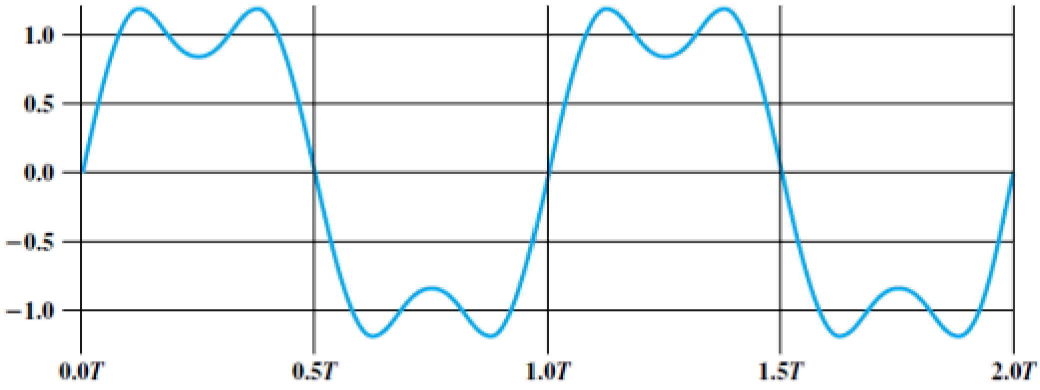


(b) Square wave

Frequency Domain Concepts

A frequency-domain plot is concerned with only the peak value and the frequency In practice, an electromagnetic signal will be made up of many frequencies. For example, the signal; $s(t) = [4/\pi] \times (\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t))$

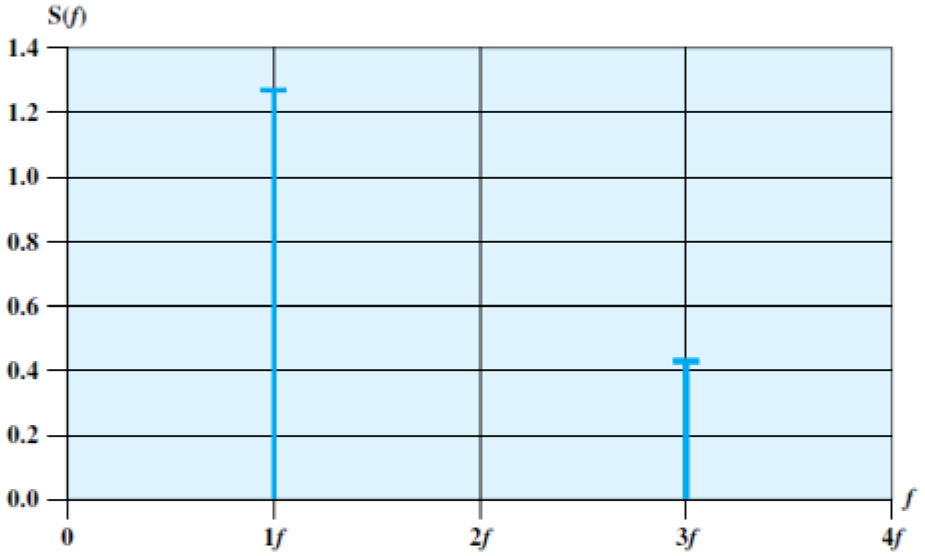
Is shown in Figure,



(c) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

The components of this signal are just sine waves of frequencies *f* and *3f*; There are two interesting points that can be made about this figure;

- The second frequency is an integer multiple of the first frequency. When all of the frequency components of a signal are integer multiples of one frequency, the latter frequency is referred to as the fundamental frequency.
- The period of the total signal is equal to the period of the fundamental frequency.



(a) $s(t) = (4/\pi)[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

The Frequency Domain Representations of the signal.

So we can say that for each signal, there is a time domain function s(t) that specifies the amplitude of the signal at each instant in time. Similarly, there is a frequency domain function S(f) that specifies the peak amplitude of the constituent frequencies of the signal.

The advantage of the frequency domain is that we can immediately see the values of the frequency and peak amplitude. A complete sine wave is represented by one spike.

The **spectrum** of a signal is the range of frequencies that it contains. For the signal of the Figure above, the spectrum extends from *f to 3f*. The **absolute bandwidth** of a signal is the width of the spectrum. In the case of the Figure, the bandwidth is *2f*.

In other words, The range of frequencies contained in a composite signal is its bandwidth.

However, Many signals have an infinite bandwidth. In such signals, most of the energy in the signal is contained in a relatively narrow band of frequencies. This band is referred to as the **effective bandwidth.**

The bandwidth is a physical property of the transmission medium that depends on, for example, the construction, thickness, and length of a wire or fiber.

Filters are often used to further limit the bandwidth of a signal. 802.11 wireless channels are allowed to use up to roughly 20 MHz

In general, The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal (Behrouz, 106).

Analog and Digital Data Transmission

The terms analog and digital correspond, roughly, to continuous and discrete, respectively. These two terms are used frequently in data communications in at least three contexts: data, signaling, and transmission.

Briefly, we define data as entities that convey meaning, or information. Signals are electric or electromagnetic representations of data. Signaling is the physical propagation of the signal along a suitable medium. Transmission is the communication of data by the propagation and processing of signals. In what follows, we try to make these abstract concepts clear by discussing the terms analog and digital as applied to data, signals, and transmission.

Analog and Digital Data

In a communications system, data are propagated from one point to another by means of electric signals. An analog signal is a continuously varying electromagnetic wave that may be propagated over a variety of media, depending on spectrum; examples are wire media, such as twisted pair and coaxial cable, fiber optic cable, and atmosphere or space propagation A digital signal is a sequence of voltage pulses that may be transmitted over a wire medium; for example, a constant positive voltage level may represent binary 1, and a constant negative voltage level may represent binary 0.

The principle advantages of digital signaling are that it is generally cheaper than analog signaling and is less susceptible to noise interference . The principle disadvantage is that the digital signals are severing more from attenuation than do analog signals.

Data and Signals

Generally, analog data are a function of time and occupy a limited frequency spectrum; such data can be represented by an electromagnetic signal occupying the same spectrum. Digital data can be represented by digital signals, with a different voltage level for each of the two binary digits.

Digital data can also be represented by analog signals by use of a modem (modulator/ demodulator). The modem converts a series of binary (two-valued) voltage pulses into an analog signal by encoding the digital data onto a carrier frequency. The resulting signal occupies a certain spectrum of frequency centered about the carrier and may be propagated across a medium suitable for that carrier. The most common modems represent digital data in the voice spectrum and, hence, allow those data to be propagated over ordinary voice-grade telephone lines. At the other end of the line, the modem demodulates the signal to recover the original data

In an operation very similar to that performed by a modem, analog data can be represented by digital signals. The device that performs this function for voice data is a codec (coder-decoder). In essence, the codec takes an analog signal that directly represents the voice data and approximates that signal by a bit stream. At the receiving end, the bit stream is used to reconstruct the analog data.

Thus, Figure below suggests that data may be encoded into signals in a variety of ways.

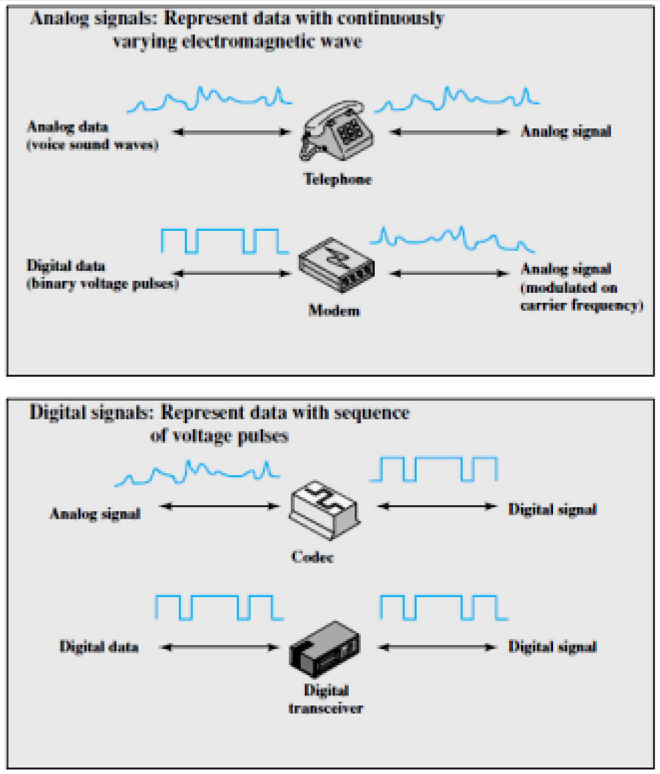


Figure 3.14 Analog and Digital Signaling of Analog and Digital Data

Analog and Digital Transmission (w84)

Both analog and digital signals may be transmitted on suitable transmission media.The way these signals are treated is a function of the transmission system. Analog transmission is

a means of transmitting analog signals without regard to their content; the signals may represent analog data (e.g., voice) or digital data (e.g., binary data that pass through a modem). In either case, the analog signal will become weaker (attenuate) after a certain distance. To achieve longer distances, the analog transmission system includes amplifiers that boost the energy in the signal. Unfortunately, the amplifier also boosts the noise components.With amplifiers cascaded to achieve long distances, the signal becomes more and more distorted. Digital transmission, in contrast, assumes a binary content to the signal. A digital signal can be transmitted only a limited distance before attenuation, noise, and other impairments endanger the integrity of the data. To achieve greater distances, repeaters are used. A repeater receives the digital signal, recovers the pattern of 1s and 0s, and retransmits a new signal. Thus the attenuation is overcome.

Both long-haul telecommunications facilities and intrabuilding (within) services have moved to digital transmission and, where possible, digital signalling techniques. The most important reasons are as follows:

- **Digital technology**: The advent of large-scale integration (LSI) and very-large scale integration (VLSI) technology has caused a continuing drop in the cost and size of digital circuitry. Analog equipment has not shown a similar drop.
- **Data integrity**: With the use of repeaters rather than amplifiers, the effects of noise and other signal impairments are not cumulative. Thus it is possible to transmit data longer distances and over lower quality lines by digital means while maintaining the integrity of the data.
- **Capacity utilization**: It has become economical to build transmission links of very high bandwidth, including satellite channels and optical fiber. A high degree of multiplexing is needed to utilize such capacity effectively, and this is more easily and cheaply achieved with digital (time division) rather than analog (frequency division) techniques.
- **Security and privacy**: Encryption techniques can be readily applied to digital data and to analog data that have been digitized.
- **Integration**: By treating both analog and digital data digitally, all signals have the same form and can be treated similarly. Thus economies of scale and convenience can be achieved by integrating voice, video, and digital data.

TRANSMISSION IMPAIRMENTS

With any communications system, the signal that is received may differ from the signal that is transmitted due to various transmission impairments.

The most significant impairments are :

- Attenuation and attenuation distortion
- Delay distortion
- Noise

Attenuation

The strength of a signal falls off with distance over any transmission medium. For guided media, this reduction in strength, or attenuation, is generally exponential and for unguided media, attenuation is a more complex function of distance and the makeup of the atmosphere. Attenuation introduces three considerations for the transmission engineer. First, a received signal must have sufficient strength so that the electronic circuitry in the receiver can detect the signal. Second, the signal must maintain a level sufficiently higher than noise to be received without error. Third, attenuation varies with frequency.

The first and second problems are dealt with by attention to signal strength and the use of amplifiers or repeaters The third problem is particularly noticeable for analog signals. Because the attenuation varies as a function of frequency, the received signal is distorted, reducing intelligibility. To overcome this problem, techniques are available for equalizing attenuation across a band of frequencies. Another approach is to use amplifiers that amplify high frequencies more than lower frequencies.

Noise

Noise is another cause of impairment. Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal. Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter. Induced noise comes from sources such as motors and appliances.

These devices act as a sending antenna, and the transmission medium acts as the receiving antenna. Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna. Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

CHANNEL CAPACITY

We have seen that there are a variety of impairments that distort or corrupt a signal. For digital data, the question that then arises is to what extent these impairments limit the data rate that can be achieved. The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the channel capacity.

There are four concepts that we are using with the capacity of the channel:

Data rate: The rate, in bits per second (bps), at which data can be communicated

Bandwidth: The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz

Noise: The average level of noise over the communications path

Error rate: The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted

DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second over a channel. Data rate depends on three factors:

1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channels another by Shannon for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

To begin, let us consider the case of a channel that is noise free. In this environment, the limitation on data rate is simply the bandwidth of the signal. A formulation of this limitation states that if the rate of signal transmission is 2B, then a signal with frequencies no greater than B is sufficient to carry the signal rate. For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \text{Log}_2 L$$

In this formula, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data or voltage levels, and BitRate is the bit rate in bits per second.

Example 3.34
Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal
levels. The maximum bit rate can be calculated as
BitRate =2 x 3000 x log2 2 =6000 bps

Example 3.35
Consider the same noiseless channel transmitting a signal with four signal levels (for each level,
we send 2 bits). The maximum bit rate can be calculated as
BitRate =2 x 3000 X log2 4 = 12,000 bps

Noisy Channel: Shannon Capacity

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel. The key parameter involved in this reasoning is the signal-to-noise ratio (SNR, or S/N),10 which is the ratio of the power in a signal to the power contained in the noise that is present at a particular point in the transmission.

Typically, this ratio is measured at a receiver, because it is at this point that an attempt is made to process the signal and recover the data. this ratio is often reported in decibels:

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

This expresses the amount, in decibels, that the intended signal exceeds the noise level. A high SNR will mean a high-quality signal and a low number of required intermediate repeaters.

The signal-to-noise ratio is important in the transmission of digital data because it sets the upper bound on the achievable data rate. Shannon's result is that the maximum channel capacity, in bits per second, obeys the equation

$$C = B \log_2(1 + \mathrm{SNR})$$

where C is the capacity of the channel in bits per second and B is the bandwidth of the channel in Hertz. The Shannon formula represents the theoretical maximum that can be achieved.

As an example, consider a voice channel being used, via modem, to transmit digital data. Assume a bandwidth of 3100 Hz. A typical value of S/N for a voice-grade line is 30 dB, or a ratio of 1000:1. Thus, C= 3100 log2 *1+1000) = 30,894 bps

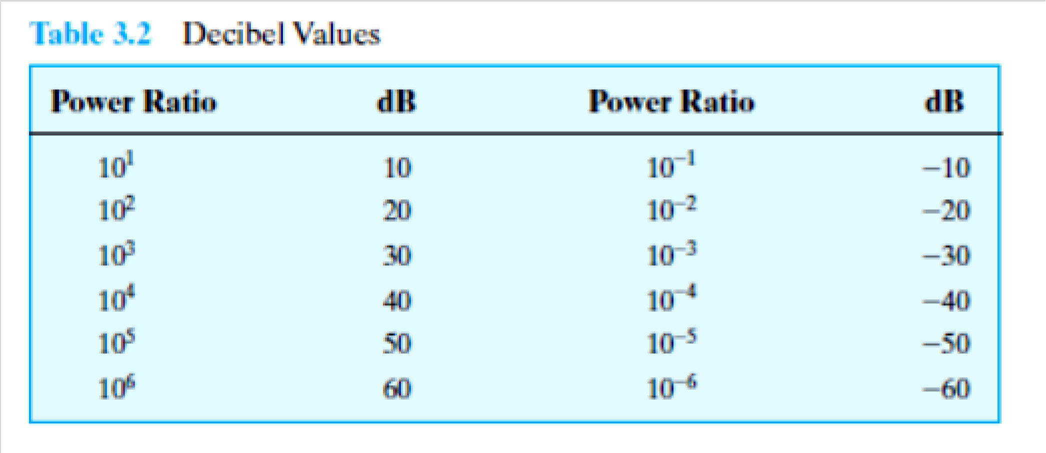


Table 3.2 Decibel Values

Power Ratio	dB	Power Ratio	dB
10^1	10	10^{-1}	−10
10^2	20	10^{-2}	−20
10^3	30	10^{-3}	−30
10^4	40	10^{-4}	−40
10^5	50	10^{-5}	−50
10^6	60	10^{-6}	−60